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ORIGINAL ARTICLE

El-Salam canal is a potential project reusing the Nile Delta drainage water for Sinai desert agriculture: Microbial and chemical water quality

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Abstract More than 12×10^9 m^3/year of Nile Delta drainage water is annually discharged into the Mediterranean Sea. El-Salam (peace) canal, having a mixture of such drainage water and the Nile water (1:1 ratio), crosses the Suez canal eastward to the deserts of north Sinai. The suitability of the canal water for agriculture is reported here. Representative samples were obtained during two successive years to follow effects of seasonal and spatial distribution, along the first 55 km course in north Sinai, on the water load of total bacteria, bacterial indicators of pollution, and chemical and heavy metals contents. In general, the canal water is acceptable for irrigation, with much concern directed towards the chemical contents of total salts (EC), Na and K, as well as the trace elements Cd and Fe. Extending the canal course further than 30 km significantly lowered the fecal pollution rate to the permissible levels of drinking water. Results strongly emphasize the need for effective pre-treatment of the used drainage water resources prior mixing with the Nile water.

Introduction

Sinai peninsula is a unique environment. Over the years, it has been subjected to flora [1–5] and microflora [6,7] investigations. With a rainfall of <100 mm a year, the major limitations for agricultural development is the available water resources. Therefore, the need arises to secure additional resources, e.g. the reuse of agriculture drainage water. At present, more than 12×10^9 m^3/year of such water is annually discharged into the Mediterranean sea [8]. In this respect, El-Salam (peace) canal is considered as a unique project brings the Nile water to the eastern deserts of north Sinai; originating from the River Nile at 210 km on Damietta branch and

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running south east ca. 89.4 km. Then, it crosses the Suez canal through a siphon to the peninsula extending 175 km eastward in north Sinai. It is planned to deliver 4.45×10^9 m^3 water, provided by the river Nile (2.11×10^9) mixed (ca. 1:1, v/v) with 2.34×10^9 m^3 from drainage water (El-Serw and Hadous drains) [9,10]. The canal is planned to provide water for the cultivation of ca. 150,000 hectares in north Sinai out of the total targeted ca. 248,000 hectares. Water is to be checked and analyzed periodically during years of plantation to monitor and readjust the ratio of mixing in the light of changes in soil and waters. So far, *in situ* and laboratory studies concentrated on the western part of the canal before crossing the Suez canal. The water quality has been checked, chemically not microbiologically, along El-Serw and Hadous drains since 1997 as well as the western course prior the Suez canal siphon [8,10–12].

Since 1992, joint governmental and international development agencies did cooperate to report on the environmental impact assessment of the canal project [13]. Among the major positive impacts of the canal project are reclaiming desert soils and development of new agro-ecological habitats, improving socio-economic conditions for native and introduced settlers, and fixation of moving sand dunes. However, the expected negative impacts include upsetting and increasing pressure on the natural ecosystems, build up of soil salinity leading to soil degradation, and increased seepage of contaminated groundwater into aquifers and Lake Bardawil. Taking into considerations such impacts, our group have already conducted research to document the diversity of flora and associated microflora in plant–soil ecosystems of the major targeted area of the canal in north Sinai [6,7,14]. The present study is primarily reporting on the water quality of the canal water and its impact on the environment of north Sinai. The suitability of water for agriculture in principle, and for drinking if possible, was investigated taking into consideration spatial distribution along the first 55 km and seasonal variations during two successive years (2003/2004 and 2004/2005).

Material and methods

Experimental sites

El Salam canal originates from Damietta city where water from River Nile (Damietta branch), Bahr Hadous Drain and El Serw Drain are mixed together by the ratio 1:1. The canal brings the water from the west of Suez canal to the east. Under the Suez canal, a siphon of four tunnels (750 m long and 5.1 m Ø) brings the already mixed water from west to east. Water samples were collected from the mouth of the siphon (0 km) and five further eastward sites up to 55 km, in north Sinai (Fig. 1).

Sampling and in situ measurements

Representative water samples were manually collected during the seasons winter, spring, summer, and autumn of two successive years (2003/2004 and 2004/2005). For microbiological analysis, surface water (ca. < 1 m ashore) samples were aseptically collected in sterile brown bottles (500 ml capacity), transported to laboratory, and stored at 4 °C until bacteriological analysis completed within 48 h of sampling. Additionally, glass stopped oxygen sampling bottles (300 ml), for dissolved oxygen as well as biochemical oxygen demand determinations, were filled carefully with water samples and fixed immediately on the spots by adding 2 ml $MnSO_4$ followed by 2 ml alkaline KI [15]. For trace elements analysis, water samples were further collected in 1 l plastic bottles, and preserved with 5 ml concentrated nitric acid on the spot and stored in refrigerator [15]. One-liter plastic bottles were also filled with water samples for undertaking the rest of chemical analysis.

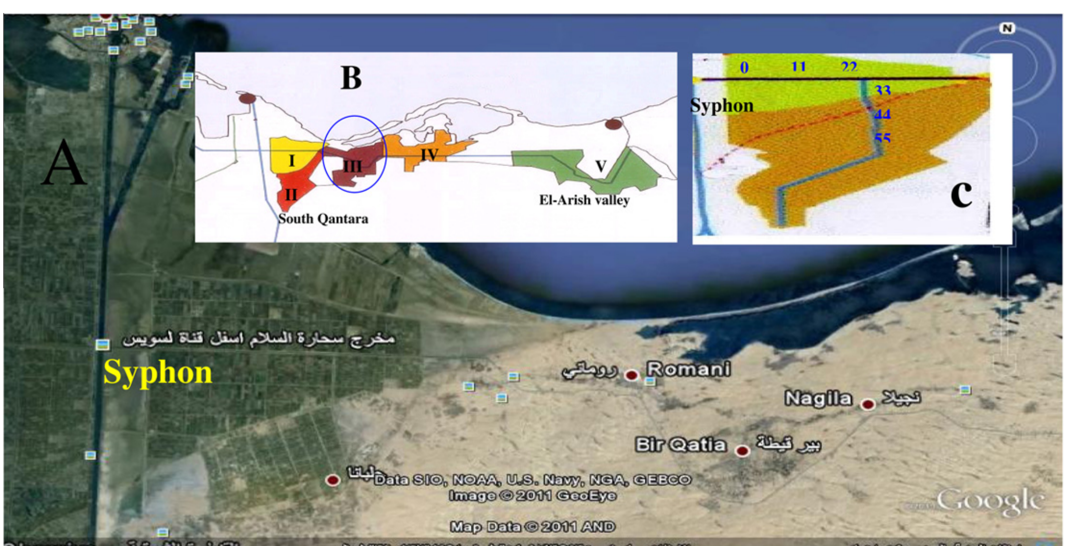


Fig. 1 El-Salam canal course in north Sinai. (A) A satellite image for the canal beginning of the El-Salam siphon under Suez canal. (B) Outline map of El-Salam canal development project, showing the course of the canal and the five (I, II, III, IV, V) future targeted cultivated areas beginning of South El-Qantara eastward to El-Arish 90. (C) The sampling six sites of the canal, 0, 11, 22, 33, 44, 55 km away of the siphon, with the following respective GPS data, N: 31°01′171″, E: 32°18′889″; N: 31°01′272″, E: 32°25′765″; N: 31°01′446″, E: 32°32′72″; N: 31°00′283″, E: 32°39′111″; N: 30°56′117″, E: 32°43′437″; N: 30°58′719″; E: 32°48′893″.

Analyses

In situ measurements

Temperature of surface water and air, pH, EC were determined *in situ* according to the Standard Methods of American Public Health Association [15], using a pH and EC meter (Jenway 4330).

Laboratory measurements

Bacteriological analyses

(a) The pour plate technique [16] and the plate count agar [15] were used for the enumeration of total culturable bacteria at both 22 and 37 °C incubation temperatures. Total spore-forming bacteria, after pasteurization of selected sample dilutions for 15 min at 80 °C, were counted by the incubation of pour plates prepared at 30 °C.

(b) Total and spore-forming diazotrophs were counted using the surface inoculated plate method and N-deficient combined carbon sources agar medium, CCM [17]. Three agar plates were inoculated from each suitable dilution and incubation took place at 30 °C for 72 h. Representative colonies were transferred to semi-solid CCM, and measured for acetylene reduction [18]. Isolates producing > 5 nmol C_2H_4 culture^{-1} h^{-1} were secured for further identification based on API 20 E (Enterobacteriacea) and 20 NE (Non-Enterobacteriaceae) profiles [6].

(c) Total and fecal coliforms were enumerated in MacConkey broth medium [15]. For presumptive test, three sets of tubes were prepared: five tubes each containing 10 ml of double strength broth [15] were inoculated with 10 ml water sample, five tubes containing 5 ml of single strength broth were inoculated with 1 ml of water, and the remaining five tubes containing 5 ml of broth were inoculated with 0.1 ml of water samples. After incubation at 37 °C, the MacConkey broth tubes were observed for gas production, and presumptive coliform numbers were estimated using the MPN index. For confirmations, sub-cultures from positive tubes were incubated in a water bath at 45.5 °C for 24–48 h, again observed for gas production, and the number of positive tubes used to calculate the MPN. Completed test using eosin methylene blue (EMB) agar was performed and plates were incubated at 44.5 °C for 24–48 h; metallic shine or pink with dark center colonies on EMB agar indicated positive results.

The recommended method [15] for detection and counting fecal streptococci in waters were applied. Azide dextrose broth medium [15] in tubes was inoculated with the suitable serial decimal dilutions of water samples, incubated at 37 °C for 48 h. A confirmation test was made by transferring three loops from the turbid positive tubes to ethyl violet azide broth and incubated at 37 °C for 72 h. Positive tubes were those having a slight turbidity accompanied with purple bottom.

Media

Plate count agar [15]

Contains (g l^{-1}): tryptone, 5.0; glucose, 1.0; yeast extract, 2.5; agar, 15; pH, 7.2.

MacConkey broth [15]

Comprises (g l^{-1}): peptone, 20.0; NaCl, 5.0; lactose, 5.0; sodium taurocholate, 5.0; bromocresole purple, 0.01; pH, 7.2.

Eosin methylene blue agar Levin's medium [15]

Contains (g l^{-1}): peptone, 10.0; lactose, 10.0; K_2HPO_4, 2.0; eosin Y, 0.4; methylene blue, 0.065; agar, 15; pH, 7.2.

Azide dextrose broth [15]

Contains (g l^{-1}): peptone, 15.0; beef extract, 4.5; NaCl, 7.5; sodium azide, 0.25; pH, 7.2.

N-deficient combined carbon sources medium, CCM [17]

Comprises (g l^{-1}): glucose, 2.0; malic acid, 2.0; mannitol, 2.0; sucrose, 1.0; K_2HPO_4, 0.4; KH_2PO_4, 0.6; $MgSO_4$, 0.2; NaCl, 0.1; $MnSO_4$, 0.01; yeast extract, 0.2; fermentol (a local product of corn-steep liquor), 0.2; KOH, 1.5; $CaCl_2$, 0.02; $FeCl_3$, 0.015; Na_2MoO_4, 0.002, $ZnSO_4$, 0.00025; $CuSO_4$, 0.00008; sodium lactate (60%, v/v) 0.6 ml^{-1}; pH, 7.0. Filter-sterilized solutions of biotin (0.5 μg l^{-1}) and *para*-amino benzoic acid (10 μg l^{-1}) were added after sterilization.

Chemical analyses

Dissolved oxygen was measured using the modified Winkler method [15], and biochemical oxygen demand (BOD) was determined with the 5-days incubation method [15]. Chemical oxygen demand (COD) was carried out using potassium permanganate method [19]. Colorimetric methods were used to determine ammonia using phenate method [15], nitrite [15], and nitrate [20].

Sodium and potassium were measured using flame emission photometric method [15]. Calcium was determined in water samples using EDTA titrimetric method [15]. Magnesium and heavy metals (cadmium, copper, iron and zinc) were determined using atomic absorption spectrometry (Perkin-Elmer 2380) after using the digestion technique by nitric acid [15].

Statistical analysis

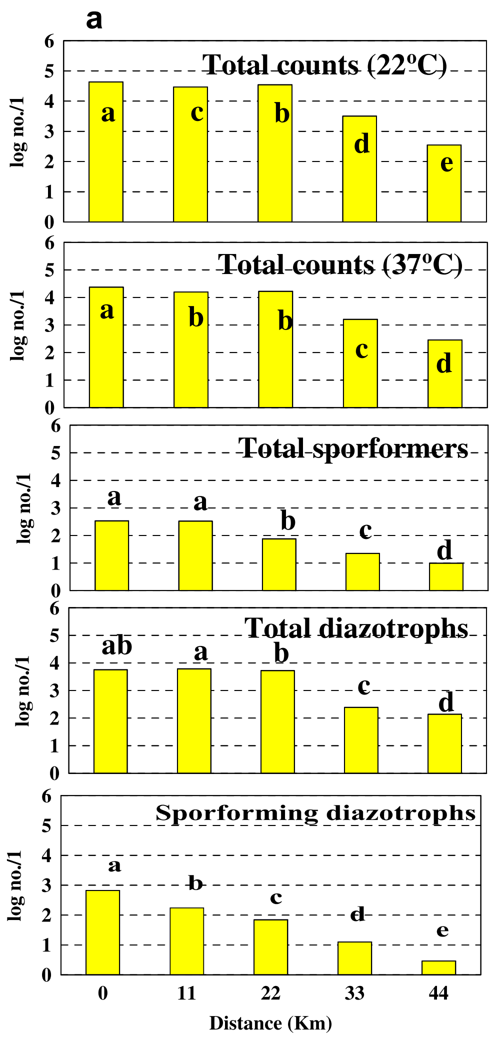
Data were statistically analyzed using analysis of variance (ANOVA) [21] and the MSTAT computer program. The correlation coefficients and linear regressions among the different parameters were computed as well.

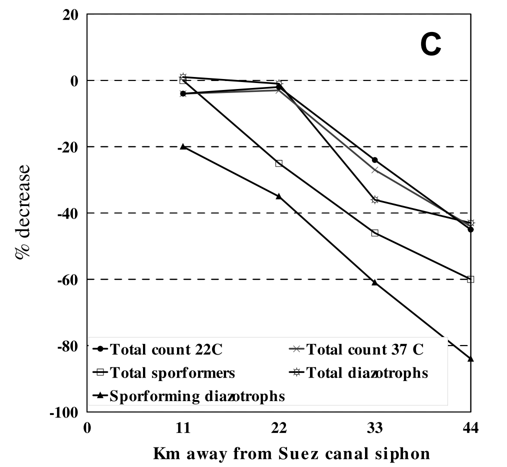
Results

Microbiological analyses

Microbial analyses included total bacterial counts developed on either 22 or 37 °C, total diazotrophs as well as spore forming bacteria and diazotrophs. ANOVA analysis indicated significant differences attributed to the years, the seasons and the sites (Fig. 2a and b). Among the years, 2003/2004 recorded the highest populations of the majority of bacterial groups. The seasonal effects are pronounced as well. Total bacteria developed on 22 °C were particularly higher in winter (> 10^3–10^4 cfu ml^{-1}) compared to other seasons. On the other hand, the mesophilic groups, including total bacteria developed on 37 °C, total diazotrophs and spore formers, were significantly the highest in spring (> 70–10^3 cfu ml^{-1}).

Fluctuations in the populations of bacterial groups along the course of the canal are presented in Fig. 2a and e. Populations decreased with the increase of canal course and percentage decreases were calculated (Fig. 2c). Compared to the zero





d

	TB 22ºC	TB 37ºC	TS	TD	SD	PH	EC	W. Temp.
TB 22ºC	1.00							
TB 37ºC	0.79*	1.00						
TS	0.32*	0.19*	1.00					
TD	0.02	0.25*	0.52*	1.00				
SD	0.52*	0.51*	0.46*	0.38*	1.00			
PH	-0.43*	-0.34*	-0.35*	-0.26*	-0.66*	1.00		
EC	-0.32*	-0.26*	-0.39*	-0.37*	-0.40*	0.29*	1.00	
W. Temp.	0.31*	0.26*	0.24*	0.02	-0.01	0.10	0.07	1.00

Marked correlations are Significant at $p < 0.05$ (n=120)

b

	Total count (22 C)	Total count (37 C)	Total sporformers	Total diazotrophs	Sporforming diazotrophs
Factor A (years)					
2004	3.539 A	3.302 A	1.609 A	2.931 A	1.903 A
2005	3.282 B	3.117 B	1.570 B	2.581 AB	1.023 B
Factor B (Seasons)					
Winter	3.878 A	3.231 C	1.494 B	2.373 C	1.551 AB
Spring	3.494 B	3.631 A	1.677 A	3.392 A	1.573 A
Summer	3.474 B	3.375 B	1.460 B	2.235 D	1.503 B
Autumn	2.795 C	2.600 D	1.727 A	3.022 B	1.227 C

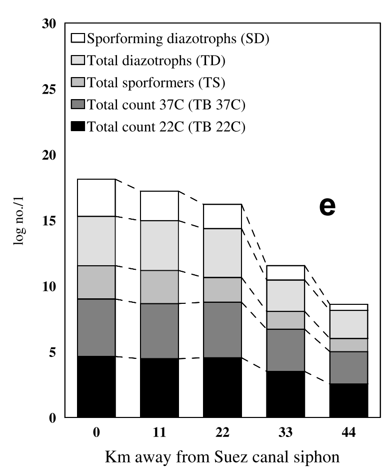


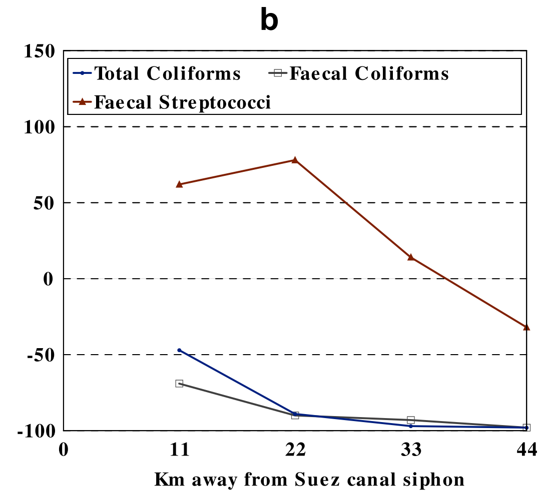
Fig. 2 Spatial changes in microbial populations (log no./l) along the course of El-Salam canal during the two successive years (n = 8 seasons). (a) Population changes in various bacterial groups by distance; (b) one-way ANOVA analysis; (c) percentage decreases in bacterial load by distance; (d) correlation matrix; (e) cumulative total bacterial load by distance; means followed by the same letter are not significantly different (p < 0.05).

point at the juncture (crossing point) of Suez canal, percentage decreases ranged from < 5% to 84%. Less than 5% decreases were reported along the first 22 km, and increased to 24–45% further to the end of the tested sites (44 km). As to spore formers, corresponding decreases were higher, 24–27% and 46–84%. The behavior of various microbial groups was alike, that was confirmed by positive correlations reported (Fig. 2d). Interactions between bacterial groups and physico-chemical parameters were computed and reported to be positive with temperature and negative with pH and EC.

Differential temperature ratio test, relating total bacterial counts on 22 °C to those on 37 °C, was applied and figures obtained did range from 0.21 to 6.25. Compared to the permissible stander of 10:1, this indicates the heavy pollution of the canal waters. Further pollution parameters indicated the presence of total and fecal coliforms as well as fecal streptococci a

Distance* \ Seasons	Winter		Spring		Summer		Autumn	
	2003	2005	2003	2004	2003	2004	2003	2004
	Total coliforms (MPN/100 ml)							
0	55	250	45	120	550	20	425	110
11	5	35	14	110	550	17	55	55
22	2	5	80	11	13	4	30	35
33	2	2	7	2	13	2	20	4
44	0	2	4	2	ND	13	ND	7
55	0	ND	35	ND	ND	ND	ND	ND
	Faecal coliforms (MPN/100 ml)							
0	0	50	8	4	70	14	4	17
11	0	11	4	5	20	6	0	5
22	0	5	7	0	0	4	0	0
33	0	2	2	0	5	0	2	0
44	0	2	0	0	ND	0	ND	0
55	0	ND	7	ND	ND	ND	ND	ND
	Faecal streptococci (MPN/100 ml)							
0	50	35	70	130	250	ND	130	0
11	25	8	17	250	250	550	130	0
22	550	25	130	250	250	25	110	11
33	20	4	35	130	250	250	110	70
44	2	20	80	250	ND	20	ND	13
55	4	ND	80	ND	ND	ND	ND	ND

* Distance from Suez canal siphon in Km.
ND, not determined



c

	TC	FC	FS
TC	1.00		
FC	0.72*	1.00	
FS	0.18	0.07	1.00
Marked correlations are Significant at $p < 0.05$ (n=120)			

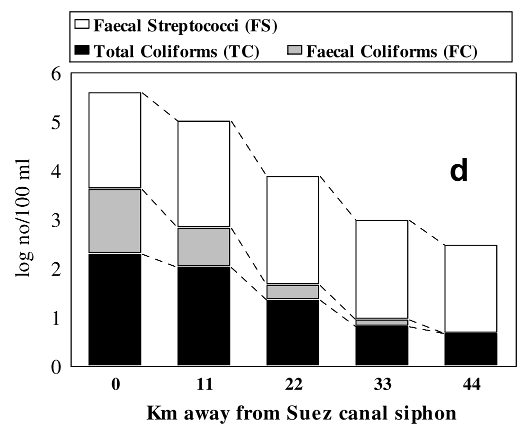


Fig. 3 Spatial changes in the populations of bacterial indicators of pollution along the course of the canal. (a) Population changes in bacterial indicators of pollution (MPN/100 ml); (b) percentage decreases in bacterial load by distance; (c) correlation matrix; (d) cumulative total bacterial load by distance.

(Fig. 3a). Irrespective of the seasons and sites, the indicators of pollution did present with population ranged from >0 to 550, >0 to 70, and >0 to 550 MPN/100 ml of total coliforms, fecal coliforms, and fecal streptococci respectively. This is an indication of the suitability of the water for irrigation not for drinking. Further than 30 km, fecal coliforms were almost absent allowing the potability of the canal water (Fig. 3b and d). The ratio between fecal coliforms and fecal streptococci ranged from 0 to 1.43 indicating the non-human sources of pollution.

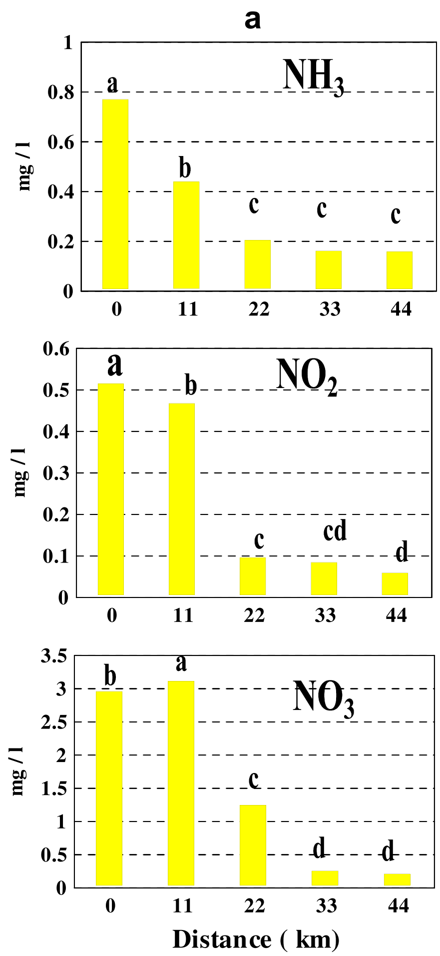
The associative nitrogen-fixing bacteria (diazotrophs) were present in appreciable numbers in the canal water (Fig. 2). Their populations represented $>66\%$ of the total bacterial population, a clear demonstration to the terrestrial supplement to the canal through agricultural drainage waters. Representative isolates of diazotrophs were single-colony purified and tested for their acetylene reducing activities. Potential isolates, having >5 nmol C_2H_4 culture^{-1} h^{-1}, were identified by API profiles (data not shown), being Gram negative representatives of *Chryseomonas meningospt*, *Chrysemonas luteola* (*Pseudomonos luteola*), *Klebsiella pneumoniae*, *Ochrobactrum anthropi*, *Pantoea* spp. (*Enterobacter agglomerans*), *Pasteurella pneumotropica*, and *Azospirillum* spp.

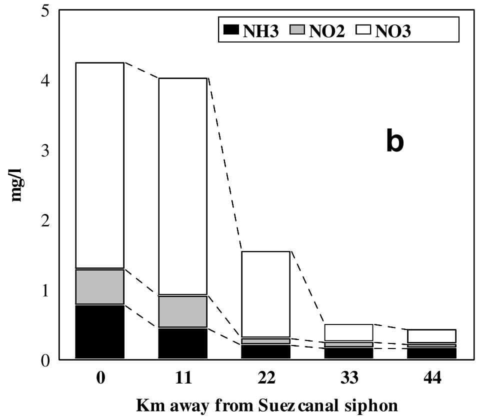
Chemical analyses

Dissolved oxygen did increase with the increase in canal distance. The turbulence and agitation of water by three pumping stations built in during the tested course of the canal may be an explanation. This pumping activates did interfere with BOD and COD (data not shown). Determinations showed increasing, not decreasing, values with the extending of the canal course.

Statistical analysis indicated significant differences in the available forms of N, attributed to years, seasons and sites (Fig. 4c). The highest concentrations were for nitrates (0.01–5.47 mg l^{-1}) followed by ammonia (0.07–1.49 mg l^{-1}) and nitrites (0.05–0.93 mg l^{-1}). Significantly, the lowest estimates were reported for the year 2004, and the season summer (Fig. 4c). Successive decreases were reported with the increase of the canal course, reaching the lowest records by the terminal site (Figs 4a and b).

Cations present in the canal water are presented in Fig. 5. Their concentrations did follow the descending order of Na^+ (75–294 mg l^{-1}) followed by Mg^{2+} and K^+ (5.0–28.0 mg l^{-1}) then Ca^{2+} (0.3–2.7 mg l^{-1}). Among seasons, the highest





c

Parameters / Factors	NH_3	NO_2	NO_3
Factor A (years)			
2004	0.354 A	0.217 A	1.070 A
2005	0.341 A	0.271 B	2.045 B
Factor B (seasons)			
Winter	0.3878 AB	0.2378 B	2.385 A
Spring	0.4159 A	0.2306 B	1.336 B
Summer	0.2409 C	0.1903 C	1.128 C
Autumn	0.3440 B	0.3186 A	1.381 B

Fig. 4 (a) Spatial changes in NH_3, NO_2, and NO_3 determinations (mg/l) along the course of El-Salam canal; (b) cumulative load of nitrogen forms; (c) one-way ANOVA analysis. Means followed by the same letter are not significantly different ($p < 0.05$).

concentrations of all cations were found in the autumn (data not shown). Interestingly enough is the successive increase in concentrations of cations except Ca^{2+} with the further extending of the canal, especially for Na^{+} (Fig. 5).

The sodium adsorption ratio (SAR), as one of the parameters used for water suitability for irrigation, ranged from 5 to 18 meq l^{-1}. The ratio increased by the extending of the canal course, being highest at the canal terminal. This makes the canal water complies with the permissible levels of this ratio, being 0–15 meq l^{-1} (data not shown).

As to the heavy metals (Fig. 6), the highest concentrations were reported for Fe (2.24–9.97 mg l^{-1}) followed by Zn (0.12–0.21 mg l^{-1}); the lowest were for both Cu and Cd (0.05–0.12 mg l^{-1}). Statistical analyses indicated significant differences attributed to fluctuations in seasons and site distances. Fe in particular significantly decreased with distance, scoring the least records further than 33 km.

Discussion

The quality of El-Salam canal water should be addressed to help monitoring and mitigating the negative impacts of the reused drainage water of the canal on the surrounding environment of north Sinai. So far, most of the follow up studies were carried out on the western part of the canal before crossing the Suez canal to north Sinai [5,8,10–12]. Therefore, the present study does complete the picture and focus on the eastern part extending in north Sinai.

El-Degwi [8] focused on the BOD parameter as a good measure for the organic load in the canal water, depending on water quality data during 1998–2001, along the first 89.4 km of the western part of the canal. They reported that BOD of El-Serw drain (21–51 mg l^{-1}) and Hadous drain (30–136 mg l^{-1}) upon mixing with the Nile water (6–34 mg l^{-1}) did elevate the BOD values of the mixed water to 24–44 mg l^{-1} before crossing the siphon under the Suez canal to north Sinai. Our results on the eastern 55 km extension of the canal showed an average of 0.01–9.88 mg l^{-1}. This agrees with the conclusions of El-Degwi et al. [8] that BOD values along El-Salam canal do comply with Egyptian environmental regulations (40 mg l^{-1} set by the governmental Law of 48/1982). International permissible limits for the use of water in irrigation are in the average of 10 mg l^{-1} [22] to 40 mg l^{-1} [23], and 2 mg l^{-1} for non-polluted rivers [24]. Statistical analysis of the data obtained in this study indicated significant differences attributed to seasons, summer and autumn being higher (3.2–4.0 mg l^{-1}) compared to spring and winter (0.7–2.4 mg l^{-1}). Fluctuations in BOD values monitored in the River Nile environment are often reported (3.7–50.2 mg l^{-1}), being affected by quantity and quality of discharges, as well as seasonal and spatial effects [25].

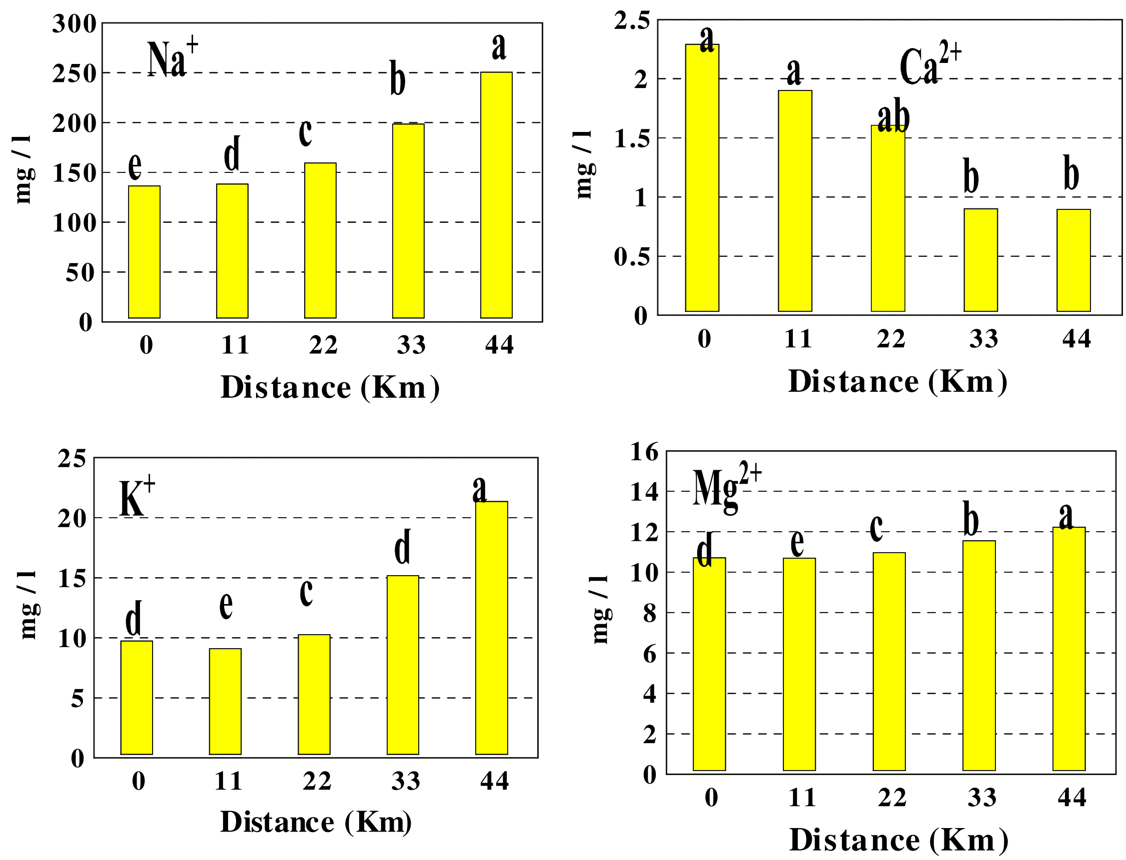


Fig. 5 Spatial changes in contents of cations (Na^-, K^+, Ca^{2+}, Mg^{2+}) along the course of El-Salam canal; means followed by the same letter are not significantly different ($p < 0.05$).

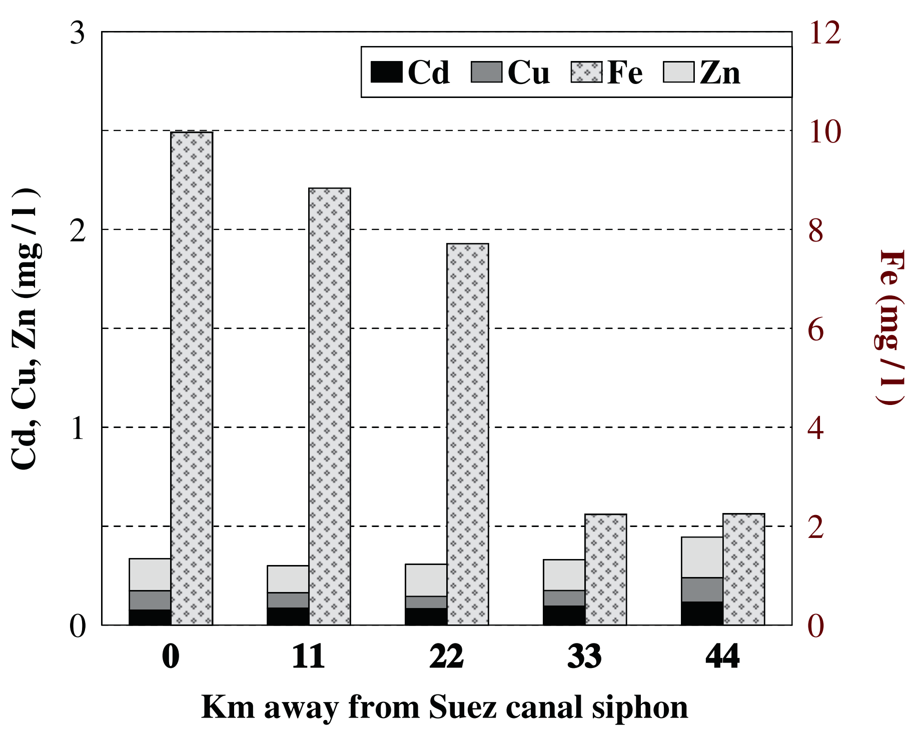


Fig. 6 Heavy metals (Cd, Cu, Fe, Zn) detected in the water along the tested course of the canal; means followed by the same letter are not significantly different ($p < 0.05$).

Table 1 Over all view on the analysis of El-Salam canal water related to international permissible limits.[a]

Parameters	Range	Permissible limits	
		Irrigation water	Drinking water
(I) Chemical analysis			
PH	8.1–9.9	6.5–8.5	6.5–8.5
EC (dSm^{-1})	**0.83–8.28**	**< 0.7– < 3**	**0.4^{EC}**
BOD ($mg\,l^{-1}$)	0.01–9.88	10^{WEF},40	NA
COD ($mg\,l^{-1}$)	1.1–18.2	75^{WEF}, 80	NA
NH_3^- ($mg\,l^{-1}$)	0.07–1.49	0–5	1.5
NO_2 ($mg\,l^{-1}$)	0.05–0.93	NA	1.0
NO_3^- ($mg\,l^{-1}$)	0.01–5.47	< 5– < 30	50
Ca^{2+} ($mg\,l^{-1}$)	0.34–2.70	0–400	100^{EC}
Mg^{2+} ($mg\,l^{-1}$)	9.4–13.5	0-60	30^{EC}
Na^+ ($mg\,l^{-1}$)	**75–294**	**0–920**	**20^{EC}–200**
SAR ($meq\,l^{-1}$)	5.05–17.82	0–15	NA
K^+ ($mg\,l^{-1}$)	**5–28**	**0–2**	**NA**
Cd ($mg\,l^{-1}$)	**0.045–0.145**	**0.01**	**0.003**
Cu ($mg\,l^{-1}$)	0.005–0.135	0.2	2.0
Fe ($mg\,l^{-1}$)	**0.13–14.10**	**5.0**	**0.3**
Zn ($mg\,l^{-1}$)	0.095–0.315	2.0	5.0
(II) Bacteriological			
Total coliforms (MPN/100 ml)	**0–550**	**NA**	**0**
Fecal coliforms (MPN/100 ml)	**0–70**	**Unrestricted irrigation (⩽ or 103)^{WHO}**	**0**
Total count 22 °C (colony/ml)	**1.30×10^2–4×10^5**	**NA**	**100^{EC}**
Total count 37 °C (colony/ml)	**0.32×10^2-3.9×10^5**	**NA**	**10^{EC}**

NA, not available.
Bold face cells are those of concern.
[a] Permissible limits are those provided by FAO for irrigation water [23] and WHO for drinking water [30]. The superscripted values: EC, European Economic Community (EC) [37]; WEF, Water Environment Federation [22].

The suitability of the canal water for irrigation is further evaluated by a number of measures. As excessive solutes in irrigation water are a common problem in semi-arid area, FAO recommends the use of the sodium adsorption ratio (SAR) to be in the range of 0–15 $meq\,l^{-1}$ [23,26]. The mixed water of El-Salam canal comply with such permissible limits and proved to be suitable for irrigation, as SAR values reported during the 2 years of the present study ranged from 5 to 18 $meq\,l^{-1}$. The ratio is shown to be affected by seasons, being higher in autumn and winter, and significantly increased as well by extending of the canal course to further than 33 km.

Certainly, extending El-Salam canal through the semi-arid desert of north Sinai is an attraction for human and animal activities. Therefore, its water quality for human consumption is of much concern, and justifies including microbial analyses in the present study. The differential temperature ratio test, rating the total bacterial counts reported on 22 and 37 °C, is a parameter to be considered and supposed to be more than 10:1 [15]. In our study, this ratio ranged from 0.66 to 2.14 indicating the pollution of the canal water. This was also confirmed by El-Khodary [13] who reported rather narrow ratios for all waters and sediments at various sites on the western part of the canal. However, a number of investigators [27] dispute the validity of this ratio in warm waters. Additional clues on imposed pollution of Hadous drain and El-Salam canal water, compared to river Nile water, was demonstrated by phycological monitoring (diversity, saprobic indices, and saprobic quotient) [28]. Identification of sources of pollution was further investigated by the detection of bacterial indicators of pollution, fecal coliform (0–70 MPN/100 ml) and fecal streptococci (> 0–550 MPN/100 ml) with a ratio ranged from 0 to 1.43, indicating the non-human sources of pollution [29]. The reported wide range of pollution is very much influenced by the nature of the water in the canal and the applied ratio of mixing the Nile water with the drainage water. This is in addition to the possible variations in the biological and chemical load of the drainage water that is affected by seasonality and potential external sources of pollution during its course in the rural areas of the Nile Delta. Extending the canal further than 30 km in north Sinai significantly lowered the fecal pollution rate to the permissible levels of drinking water. A direct clue on the ability of the canal water of self-purification by traveling such distance under this particular semi-arid conditions.

The ammonia–nitrite–nitrate concentrations in groundwater and surface water is normally low but can reach high levels as a result of leaching or runoff from agricultural land or contamination from human or animal wastes [23,30]. Ammonia (0.07–1.5 $mg\,l^{-1}$) and nitrate (0.01–5.47 $mg\,l^{-1}$) concentrations are found to be within the permissible limits. The higher contents of nitrite (0.06–0.93 $mg\,l^{-1}$) are indication to the microbial activity, and may be intermittent. This is explained by the higher microbial load of the tested canal water compared to the non-polluted River Nile water [31].

Aquatic contamination by heavy metals is very harmful since these elements are not degradable in the environment and may accumulate in the living organisms [32,33]. Industrial residues are presently one of the greatest and most diversified sources to heavy metal introduction in the water environment, and their concentration in this medium varies with the type of effluent treatment. Discharge of metal effluents into rivers may cause deleterious effects to the health [34]. Chemical analysis of

El-Salam canal water indicated that concentrations of Cu, Zn are within the permissible levels for irrigation and drinking water (Table 1). While on average, Cd and Fe concentrations exceeded the permissible levels for both irrigation and drinking. The high concentrations of Cd (.045–0.145 mg l^{-1}) are additional evident for the industrial pollution of the drainage water used, and that the wastewater treatment of mixed drainage water was not adequate to avoid metal discharge into the environment. Abdo [35] reported high concentrations of heavy metals in the Damietta branch sediments, following the order Fe > Mn > Cu > Zn > Pb > Cd. Such levels of potential pollutants are expected taking into consideration that the canal carries the wastewater of the dense cultivated Nile Delta with its high load of agrochemical residues as well as terrestrial materials including microorganisms. This in addition to the uncontrolled disposal of industrial and human activities into the drainage system in this part of the Delta, where the canal originates and receives its share of water resources.

In conclusion, the general picture is summarized in Table 1. Results of the chemical and microbiological analyses are related to the permissible levels of FAO [23], WHO [30] and Mediterranean countries [36]. The canal water is generally acceptable for irrigation; however, special concern is not directed towards microbial load (fecal coliforms) but the chemical contents of total salts (EC), Na and K, as well as the trace elements Cd and Fe. The potability of water is disputable along the first 30 km, in view of its higher load of total bacteria, and total and fecal coliforms. This is in addition to the chemical content of total salts, Na, Fe, and Cd. Our results clearly indicate the urgent need for effective strategies for the treatment of the drainage water resources before mixing with the Nile water.

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References

[1] Täckholm V. Students' Flora of Egypt. Cairo University: Beirut Publishing; 1974.
[2] Danin A. Desert vegetation of Israel and Sinai. Jerusalem: Cana. Publ. House; 1983.
[3] Gibbali MA. Studies on the flora of northern Sinai. M.Sc. Thesis. Fac. Science. Egypt: Cairo Univ.; 1988. p. 393.
[4] Boulos L. Flora of Egypt. Geraniaceae-Boraginaceae, vol. 2. Cairo, Egypt: Al Hadara Publishing; 2000.
[5] Serag MS, Khedr AA. Vegetation–environment relationships along El-Salam Canal, Egypt. Environmetrics 2001;12:219–32.
[6] Othman AA, Amer MW, Fayez M, Monib M, Hegazi NA. Biodiversity of diazotrophs associated to the plant cover of north Sinai deserts. Arch Agron Soil Sci 2003;49:683–705.
[7] Othman AA, Amer MW, Fayez M, Monib M, Hegazi NA. Biodiversity of microorganisms in semi-arid soils of north Sinai deserts. Arch Agron Soil Sci 2003;49:241–60.
[8] El-Degwi AMM, Ewida FM. Gawad SM. Estimating BOD pollution rates along El-Salam canal using monitored water quality data (1998–2001). In: Proceedings of 9th international drainage workshop, Paper No 50. The Netherlands, Utrecht, September 10–13; 2003.
[9] Mostafa AM. Development of water quality indicators and atlas of drainage water quality using GIS tools. CIDA-DRTPC-MWRI. Technical report submitted to the NAWQAM project-Egypt; 2002. p. 85.
[10] Mostafa AM, Gawad ST, Gawad SM. Development of water quality indicators for Egyptian drains. ICID, Montreal, Canada, Paper No. Q50/R6.01; 2002.
[11] Mostafa AM. GIS analysis of the NWQM data with emphasis on WWTP. CIDA-DRTPC-MWRI. Technical report submitted to the NAWQAM project-Egypt; 2001. p. 151.
[12] Rabeh SA. Monitoring of microbial pollution in El- Salam Canal, Egypt. J Egypt Acad Soc Environ Develop 2001;2:117–27.
[13] EL-Khodary NM. Northern Sinai agricultural development project environmental impact assessment (executive summary) [Online]. <http://www.cedar.at/unep/eia/docs/sinai.html#summary/>, 1992 [Cited 30.01.08].
[14] Othman AA, Fayez M, Monib M, Wafaa Amer M, Ragab M, Fendrid I, et al.. Diversity of major microbial croups and diazotrophs in the soil–plant system of north Sinai. In: Fayez M, Hegazi NA, editors. Proceedings of the symposium on agro-technologies based on biological nitrogen fixation for desert agriculture. Giza: Cairo university Press; 2000. p. 45–67.
[15] APHA (American Public Health Association). Standard methods for the examination of water and wastewater. 2nd ed. Berlin: Springer; 1995.
[16] Parkinson D, Gray TRG, Williams ST. Methods for study the ecology of soil micro-organisms. IBP Handbook No. 19; 1971.
[17] Hegazi NA, Hamza MA, Osman AA, Ali SM, Sedik MZ, Fayez M. Modified combined carbon N-deficient medium for isolation, enumeration and biomass production of diazotrophs. In: Malik KA, Mirza MS, Ladha JK, editors. Proceedings of the 7th international symposium on nitrogen fixation with non-legumes. Kluwer Academic Publishers; 1998. p. 247–53.
[18] Hegazi NA, Amer HA, Monib M. Studies on N_2-fixing spirilla (*Azospirillum* spp.) in Egyptian soils. Rev Ecol Biol Sol 1980;17:491–9.
[19] Golterman HL. Method for chemical analysis of fresh water. Oxford and Edinburgh: Blackwell Scientific Publications; 1971.
[20] Mullin JB, Riley JP. The spectrophotometric determination of nitrate in natural waters, with particular reference to sea-water. Anal Chim Acta 1955;12:464–80.
[21] Power P, Freed R, Goetz S, Reicoskg D, Smail VW, Wolberg PW. MSTAT microcomputer statistical program for design, management and analysis of agronomic research experiments. Version 4.0 Michigan State University; 1982.
[22] WEF (Water Environment Federation). Using reclaimed water to augment potable water resources. Alexandria, VA, USA; 1998.
[23] Ayers RS, Wescot DW. Water quality for agriculture, FAO Irrigation and Drainage Paper 29. Rome, Italy; 1994.
[24] Stanners D, Bourdeau P, editors. Europe's environment. The Dobbris assessment. Compiled by Eurostat together with other organizations; 1995. p. 455.
[25] Abdelhamid MI, Shaabandessouki SA, Skulberg OM. Water-quality of the River Nile in Egypt. 1: Physical and chemical characteristics. Arch Hydrobiol 1992;3:283–310.
[26] Jurdi M, Korfali Karahagopian SIY, Davies B. Evaluation of water quality of the Qaraaoun reservoir, Lebanon suitability for multipurpose usage. Environ Monit Assess 2002;77:11–30.
[27] Rai H, Hill G. Bacteriological studies on Amazon Mississippi and Nile waters. Arch Hydrobiol 1978;81:445–61.
[28] El-Sheekh MM, Deyab MAI, Desouki SS, Eladl M. Phytoplankton compositions as a response of water quality in El Salam canal Hadous drain and Damietta branch of river Nile Egypt. Pak J Bot 2010;42(4):2621–33.

[29] Feachem R. An improved role for faecal coliform to faecal streptococci ratios in the differentiation between human and nonhuman pollution sources. Water Res. 1975;9:689–90.
[30] WHO, Guidelines for drinking-water quality, incorporating first addendum. Recommendations. 3rd ed. vol. 1. Geneva: World Health Organization; 2006. p. 515.
[31] Ali SM, Sabae SZ, Fayez M, Monib M, Hegazi NA. The influence of agro- industrial effluents on River Nile pollution. J Adv Res 2011;2(1):85–95.
[32] Taylor HE, Shiller AM. Mississippi river methods comparison study: implication for water quality monitoring of dissolved trace elements. Environ Sci Technol 1995;29:1313–7.
[33] Zarazua G, Ávila-Pérez P, Tejeda S, Barcelo-Quintal I, Martínez T. Analysis of total and dissolved heavy metals in surface water of a Mexican polluted river by Total Reflection X-ray Fluorescence Spectrometry. Spectrochim Acta B 2006;61:180–4.
[34] Tavares TM, Carvalho FM. Avaliação de exposição de populaçães humanas a metais pesados no ambiente: exemplos do Recôncavo Baiano'. Química Nova 1992;15:147–54.
[35] Abdo MH. Distribution of some chemical elements in the recent sediments of Damietta branch, River Nile, Egypt. J Egypt Acad Soc Environ Develop 2004;5:125–46.
[36] Bahir A, Brissaud F. Setting up microbiological water reuse guidelines for the Mediterranean. Water Sci Technol 2004;50:39–46.
[37] European Economic Community (EC): Dir. 98/83: Council Directive of 3 November 1998 on the quality of water intended for human consumption. Off J Eur Commun 1998;L 330:32–56.